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Simulations for Computer Centerline Approach

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August 1989

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16. Abstract

Position computation for any Microwave Landing System (MLS) Area Navigation (RNAV) approach has an associated accuracy. This accuracy is affected by several error sources: MLS signal source errors, data word granularity in describing MLS ground station siting, and the MLS RNAV coordinate transformation algorithm. The International Civil Aviation Organization (ICAO) signal source errors and allowable degradation, specified in ICAO Annex 10, were used in their simulations. Since the coordinate transformation algorithms are nonlinear, it is necessary to use Monte Carlo simulation techniques to determine the magnitude of position determination accuracy in the presence of MLS signal source errors.

This report presents the results of simulations undertaken by the Federal Aviation Administration (FAA) Technical Center to determine the accuracy of the RNAV at the Categories I and II minima, and at 50 feet above ground level for Category III in the presence of the MLS signal source errors and associated allowable error degradation.

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This report presents the results of simulations undertaken by the Federal
Aviation Administration (FAA) Technical Center to determine the accuracy of the
Microwave Landing System (MLS) Area Navigation (RNAV) at the Categories I and II
minima, and at 50 feet above ground level for Category III in the presence of the
MLS signal source errors and associated allowable error degradation.

This simulation was performed to provide information on accuracy for computed
centerline operations to the International Civil Aviation Organization's (ICAO)
All Weather Operations Panel (AWOP). These results were presented to the ICAO
AWOP working group A in Canberra, Australia, May 22 through June 2, 1989.

Position computation for any MLS RNAV approach has an associated accuracy. This
accuracy is affected by several error sources: MLS signal source errors, data
word granularity in describing MLS ground station siting, and the MLS RNAV
coordinate transformation algorithm. The ICAO MLS signal source errors and
allowable degradation, specified in ICAO Annex 10, were used in these
simulations. Since the coordinate transformation algorithms are nonlinear, it
was necessary to use Monte Carlo simulation techniques to determine the magnitude
of position determination accuracy in the presence of MLS signal source errors.

INTRODUCTION

PURPOSE.

The purpose of this report is to document the results of analytical simulations for computed centerline approaches undertaken by the Federal Aviation Administration (FAA) Technical Center to provide information to the International Civil Aviation Organization's (ICAO) All Weather Operations Panel (AWOP). This report, in the form of an information paper, was presented at the fourth meeting of ICAO AWOP working group B in Canberra, Australia, May 22 through June 2, 1989.

BACKGROUND.

Computed centerline approaches fall into two classes: those conducted to the primary sited runway, and those conducted to runways other than the instrumented runway. This report addresses both classes of computed centerline approaches, although it is assumed that Category III operations would be conducted to the primary sited runway and would not require computed vertical position in the region of runway threshold.

Position computation for any Microwave Landing System (MLS) Area Navigation (RNAV) approach has an associated accuracy. This accuracy is affected by several error sources: MLS signal source errors, data word granularity in describing MLS ground station siting, and the MLS RNAV coordinate transformation algorithm. Since the coordinate transformation algorithms are nonlinear, it is necessary to use Monte Carlo simulation techniques to determine the magnitude of position determination accuracy in the presence of MLS signal source errors.

DISCUSSION

All the errors for azimuth, elevation and Precision Distance Measuring Equipment (DME/P) are taken directly from ICAO Annex 10. Azimuth guidance path following error (PFE) and allowed degradation are summarized in table 1. Elevation guidance PFE and allowed degradation are summarized in table 2. The allowable errors on the runway centerline extended for all modes of standards 1 and 2 for DME/P are shown in table 3.

The ground siting geometry for these simulations were varied. In all cases the azimuth station and DME/P station were assumed to be collocated. The elevation station was located 400 feet from the runway centerline. The azimuth station location offset ranged from 0 feet to a maximum offset, based on the MLS accuracy values used, from runway centerline, in steps of 50 feet. The maximum offset value for each combination of accuracies is shown in table 4. The distance between the azimuth and elevation stations varied from 6,000 to 10,000 feet, in steps of 1,000 feet. All ground stations were given a phase center height of 8 feet above the MLS datum point.

Two different position reconstruction algorithms were used for these simulations. The same perturbed data were passed to each of the algorithms to determine the impact of algorithm assumptions on position determination. Each of these

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algorithms comes from RTCA document DO-198 "Minimum Operational Performance standards for Airborne MLS Area Navigation Equipment." The algorithms selected were Cases 9 and 12. Since these position reconstruction algorithms are non-linear, Monte Carlo sampling techniques were employed for this simulation. The same methods were used at each of the three category analysis points.

The theoretical points used for these simulations were the 200-foot decision height (DH) for Category I, the 100-foot DH for Category II, and the 50-foot Approach Reference Datum (ARD) location for Category III. These points are located on a 3° approach to the MLS datum point. Category tolerances for evaluation of the resulting data were: ±35 feet lateral and ±10 feet vertical for Category I; ±25 feet lateral and ±5 feet vertical for Category II; and ±20 feet lateral for Category III. No vertical tolerance for Category III MLS positioning is used because systems other than the MLS will be used for vertical placement in the region of ARD.

RESULTS

The analytical results include conditions which would lie outside azimuth coverage without a rotated azimuth antenna. Summarized results from the simulation are presented in tables 5 through 12. These tables show the maximum allowed azimuth station offset permitted by the associated ground station accuracies, category tolerances, and azimuth to elevation distances for 2 sigma crosstrack and vertical errors. Accuracies stated are the station accuracies at ARD. The word ALL means that all the tested azimuth offsets met Category tolerances (see table 4 for maximum tested offsets). In the case of Category III operations, it is assumed that these approaches would only be performed to the primary sited runway and, therefore, the vertical error is driven by systems other than the MLS RNAV.

Tables 5 through 8 present the results for crosstrack error, while tables 9 through 12 present the results for vertical error.

Tables 5 and 9 are for 100-foot DME/P, 20-foot azimuth, and 2-foot elevation accuracies. Tables 6 and 10 are for 40-foot DME/P, 20-foot azimuth, and 2-foot elevation accuracies. Tables 7 and 11 are for 100-foot DME/P, 13.5-foot azimuth, and 2-foot elevation accuracies. Tables 8 and 12 are for 40-foot DME/P, 13.5-foot azimuth, and 2-foot elevation accuracies.

Several data collection flights were performed at the FAA Technical Center with an azimuth offset of 500 feet. The DME/P system was a preproduction E-system DME/P, and was collocated with the azimuth station. Preliminary comparison of the azimuth, elevation, and DME/P PFE from the flight data with the PFE from the simulation model was done. Figure 1 presents a composite plot of the Azimuth PFE data derived using the ICAO PFE filter. Also shown on this plot are the 95 percent probability envelopes that are derived from the ICAO accuracies and degradation for azimuth. Envelopes for both the 20-foot accuracy and the 13.5-foot recommended accuracy are shown. Figure 2 presents a composite plot of the elevation PFE data derived from the ICAO PFE filter contrasted with the 95 percent probability envelope permitted by the 2-foot elevation accuracy and its allowable degradation. Figure 3 presents a composite plot of the DME/P PFE data from the ICAO PFE filter. In this plot both the 95 percent envelopes for the

100-foot and for the 40-foot accuracies are shown. All three figures show that the accuracy and degradation allowances in ICAO Annex 10 are very conservative and, in turn, provide a conservative MLS signal source error model.

The results of this simulation, in their entirety, are on file in the Airborne Systems Technology Branch (ACD-330), Concepts Analysis Division, FAA Technical Center, Atlantic City International Airport, NJ 08405.

CONCLUSIONS

Computed centerline approaches to runways with offset azimuth siting configurations are possible given the performance demonstrated at each of the category approach minima. Based on the accuracies and degradations permitted in Annex 10, azimuth accuracies of 20 feet at ARD allow azimuth offsets greater than 1,000 feet for Category I computed centerline approaches with typical azimuth to elevation separations (greater than or equal to 8,000 feet). For Category II operations, only large azimuth to elevation separations (10,000 feet) permit offset siting configurations. Category III operations require centerline azimuth siting.

As the accuracies are tightened (azimuth accuracy of 13.5 feet at ARD and DME/P accuracy of 40 feet), large azimuth offsets (greater than 4,000 feet for Category I, greater than 2,000 feet for Category II, and greater than 1,000 feet for Category III) are permitted with short azimuth to elevation separations (less than 8,000 feet) for all categories of operation. For typical azimuth to elevation separations, even larger azimuth station offsets are permitted for all categories of operations (greater than 5,000 feet for Category I and greater than 3,000 feet for Categories II and III).

COMPOSITE PLOT OF ACTUAL PFE DATA
AZIMUTH STATION OFFSET APPROX. 500 FEET
MODEL ENVELOPE FOR AZ 13.5 FOOT ARD PFE - SOLID LINES
MODEL ENVELOPE FOR AZ 20 FOOT ARD PFE - DASHED LINES

FIGURE 1.   COMPOSITE PLOT OF AZIMUTH PFE DATA FROM FLIGHT
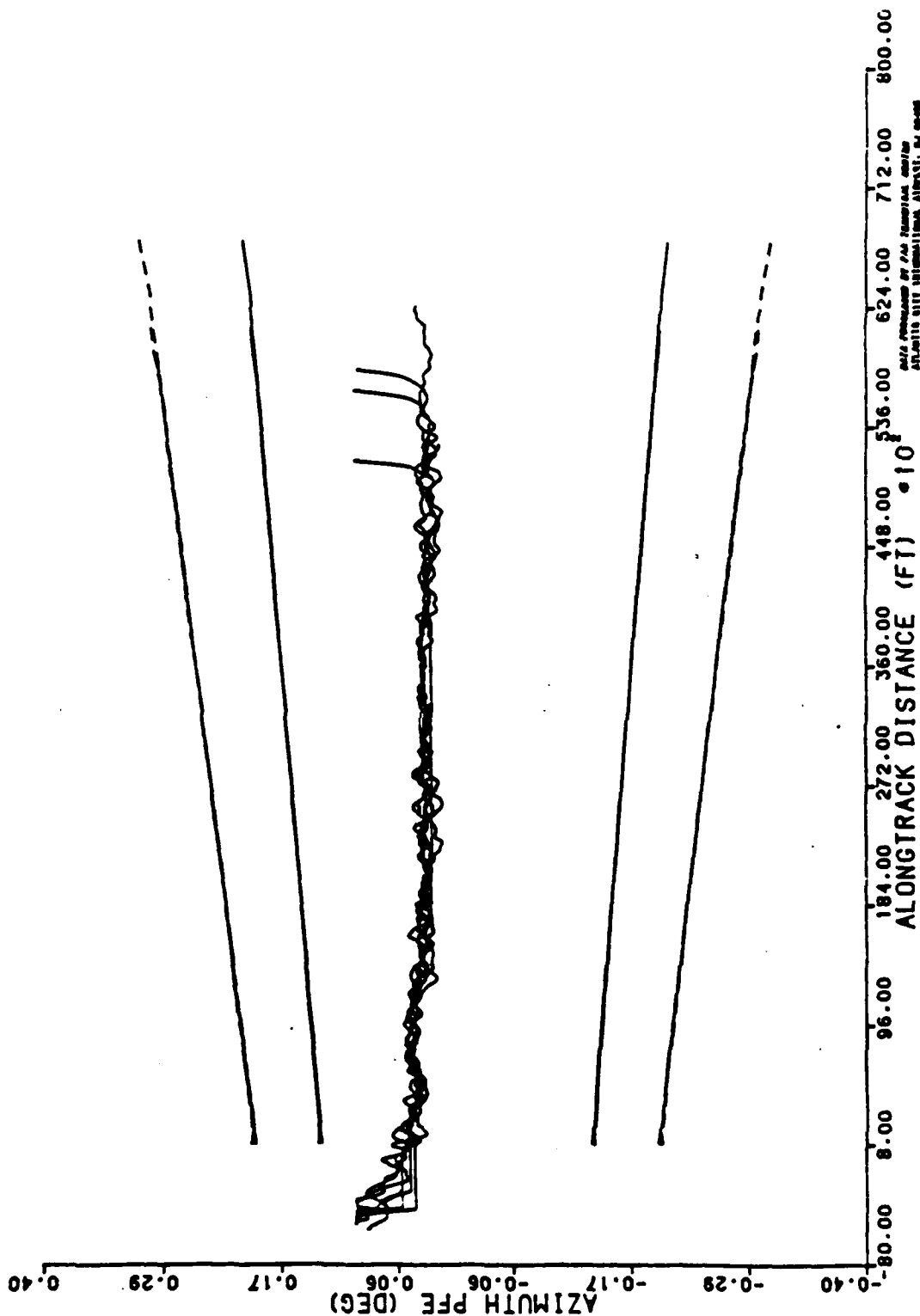TESTS WITH AN AZIMUTH OFFSET OF 500 FEET

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COMPOSITE PLOT OF ACTUAL PFE DATA
AZIMUTH STATION OFFSET APPROX. 500 FEET
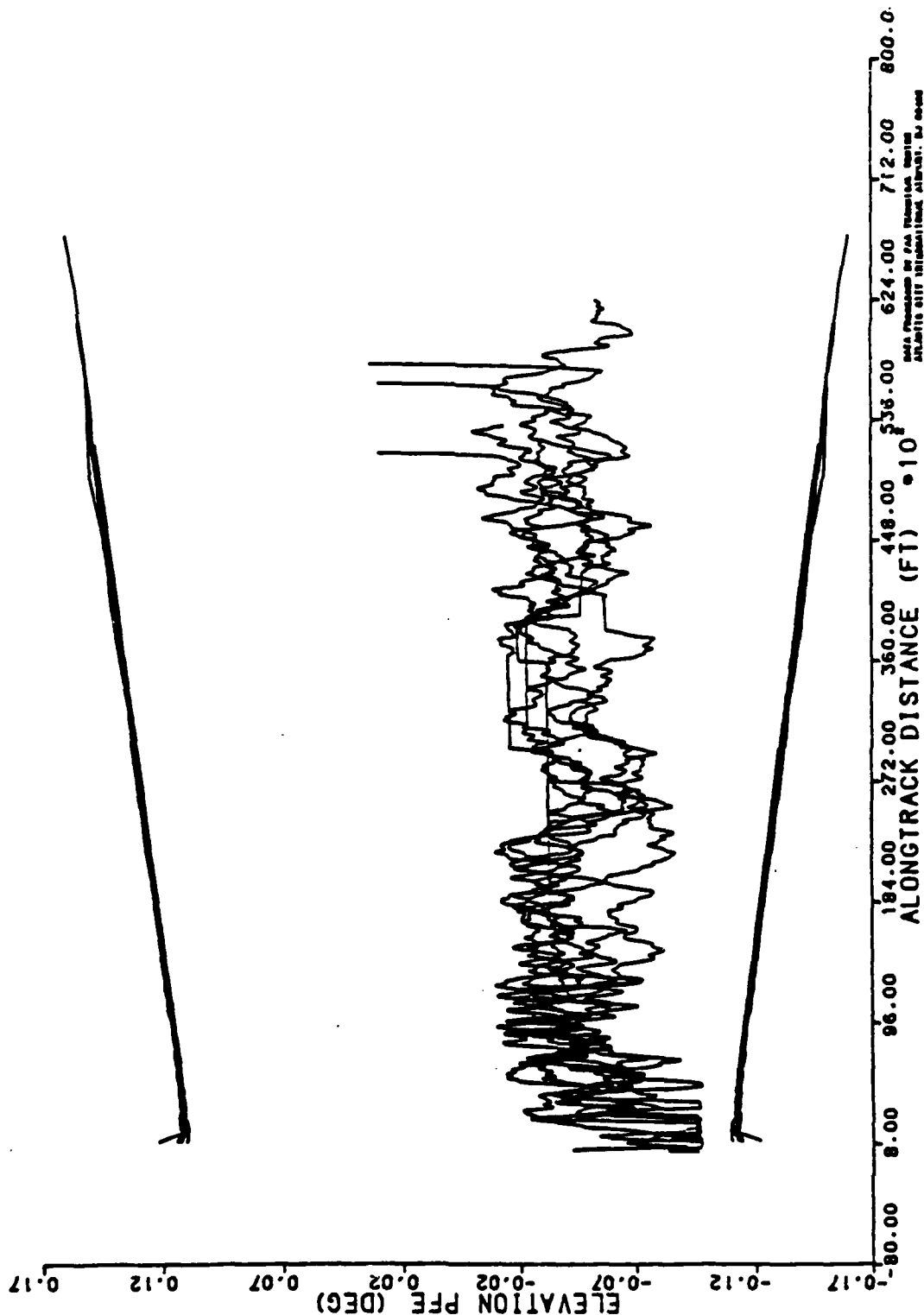MODEL ENVELOPE FOR EL 2 FOOT ARD PFE - SOLID LINES

FIGURE 2.   COMPOSITE PLOT OF ELEVATION PFE DATA FROM FLIGHT
TESTS WITH AN AZIMUTH OFFSET OF 500 FEET

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FIGURE 3. COMPOSITE PLOT OF DME/P PFE DATA FROM FLIGHT
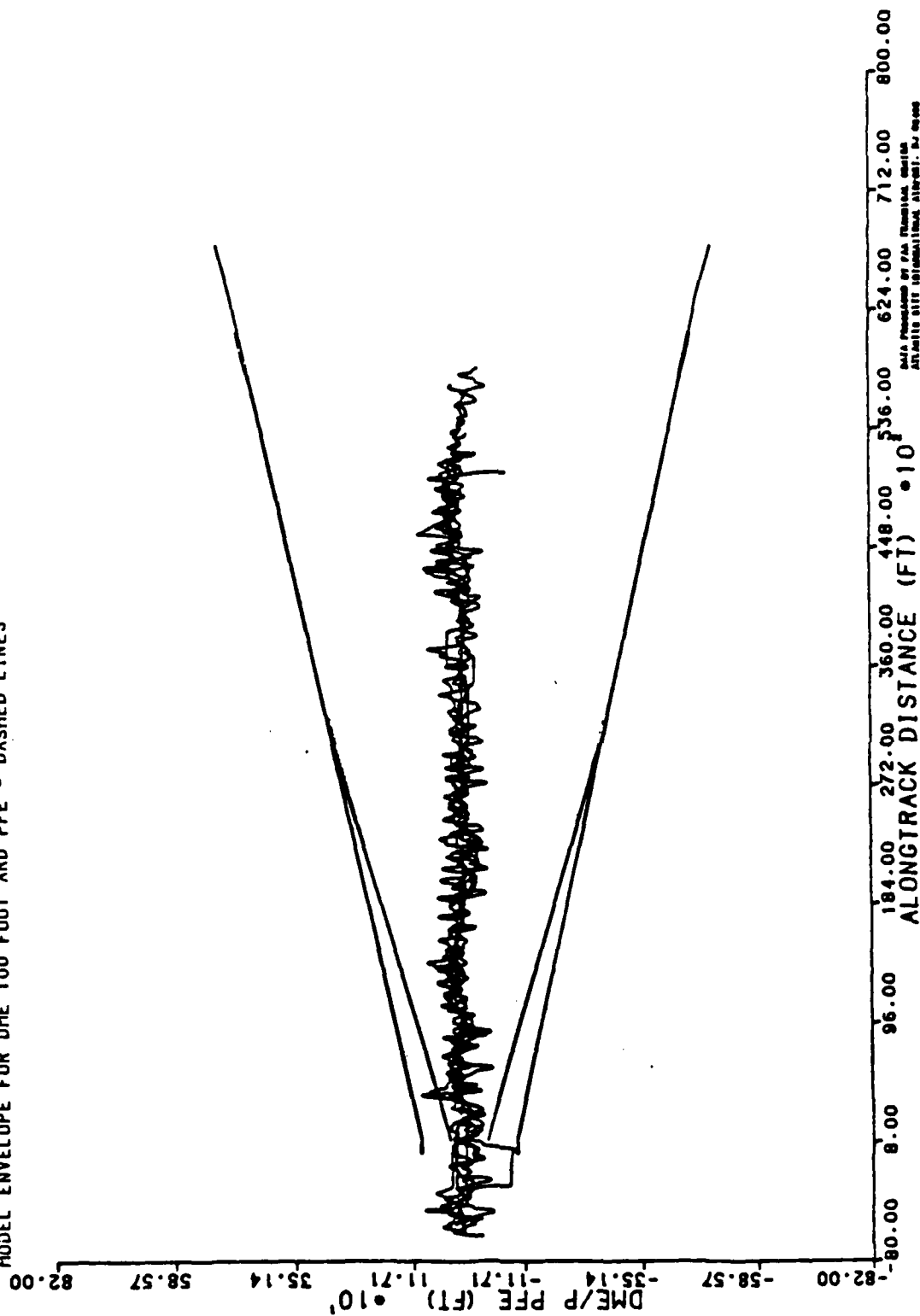TESTS WITH AN AZIMUTH OFFSET OF 500 FEET

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TABLE 1. ALLOWABLE AZIMUTH ERROR

Error at ARD	Range Induced Degradation	Azimuth Induced Degradation	Elevation Induced Degradation
+/-20 feet			At or below 9 degrees: No degradation permitted
	Linear to 2 times the error value at ARD, at 20 nmi from ARD on the runway centerline extended	Linear to 1.5 times the error value on the runway centerline extended, at the same distance from ARD	Above 9 degrees to 15 degrees: Linear to 2 times the error value permitted below 9 degrees at the same distance from ARD
+/-13.5 Feet			

Note: ARD is the acronym for Approach Reference Datum.

TABLE 2. ALLOWABLE ELEVATION ERROR

Error at ARD	Range Induced Degradation	Azimuth Induced Degradation	Elevation Induced Degradation
+/-2 Feet	Linear to 0.2 degrees at 20 nmi on the runway centerline extended along the minimum glidepath (MGP)	Linear to 1.3 times the error value on the runway centerline extended at the same distance from the ARD, at +/-40 degrees	Above MGP or 3 degrees (whichever is less): Linear to 2 times the error value at ARD, at 15 degrees Below 60 percent of MGP: linear to 6 times the error value at ARD, at limit of coverage -- not to exceed 0.8 degree

Note: It is recommended that degradation below 60 percent of MGP should be: Linear to 3 times the value at ARD at the limit of coverage and not to exceed 0.35 degrees.

TABLE 3. ALLOWABLE DME/P ERRORS

Location	Standard	Mode	Error
20 nmi to 5 nmi from ARD	1 and 2	IA	+/-820 feet reducing linearly to +/-279 feet
5 nmi to ARD	1	FA	+/-279 feet reducing linearly to +/-100 feet
5 nmi to ARD	2	FA	+/-279 feet reducing linearly to +/-40 feet
5 nmi to ARD	1 and 2	IA	+/-328 feet

Note: No degradation permitted with elevation angle. Degradation permitted with azimuth angle: Linear to 1.5 times the value of runway centerline extended at +/-40 degrees.

TABLE 4. MAXIMUM TESTED AZIMUTH STATION OFFSETS

DME/P Accuracy (feet)	Azimuth Accuracy (feet)	Elevation Accuracy (feet)	Maximum Azimuth Offset Tested (feet)
+/-328	+/-20	+/-2	1000
+/-328	+/-13.5	+/-2	1400
+/-100	+/-20	+/-2	2600
+/-100	+/-13.5	+/-2	3800
+/-40	+/-20	+/-2	4950
+/-40	+/-13.5	+/-2	7700

TABLE 5. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
CROSSTRACK ERROR DATA FOR 100-FOOT DME/P ACCURACY,
20-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION
ACCURACY

Category	Azimuth to Elevation Distance (Feet)				
	6000	7000	8000	9000	10000
I	0	0	1300	1800	2450
II	0	0	0	0	450
III	0	0	0	0	0

TABLE 6. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
CROSSTRACK ERROR DATA FOR 40-FOOT DME/P ACCURACY,
20-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION ACCURACY

Category	Azimuth To Elevation Distance (Feet)				
	6000	7000	8000	9000	10000
I	0	0	2450	3500	4800
II	0	0	0	0	1050
III	0	0	0	0	0

TABLE 7. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
CROSSTRACK ERROR DATA FOR 100-FOOT DME/P ACCURACY,
13.5-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION
ACCURACY

Category	Azimuth to Elevation Distance (Feet)				
	6000	7000	8000	9000	10000
I	2100	2450	2850	3350	3650
II	1100	1450	1600	1950	2200
III	600	900	1150	1300	1450

TABLE 8. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
CROSSTRACK ERROR DATA FOR 40-FOOT DME/P ACCURACY,
13.5-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION
ACCURACY

Category	Azimuth to Elevation Distance (Feet)				
	6000	7000	8000	9000	10000
I	4200	4900	5800	6850	7600
II	2250	3450	3750	4700	5300
III	1550	2400	3050	3400	3850

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TABLE 9. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
          VERTICAL ERROR DATA FOR 100-FOOT DME/P ACCURACY,
          20-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION
          ACCURACY

	Azimuth to Elevation Distance (Feet)				
Category	6000	7000	8000	9000	10000
I	All	All	All	All	All
II	0	0	0	0	0

TABLE 10. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
           VERTICAL ERROR DATA FOR 40-FOOT DME/P ACCURACY,
           20-FOOT AZIMUTH ACCURACY, AND 2-FOOT ELEVATION
           ACCURACY

	Azimuth to Elevation Distance (Feet)				
Category	6000	7000	8000.	9000.	10000.
I	All	All	All	All	All
II	All	All	All	All	All

TABLE 11. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
           VERTICAL ERROR DATA FOR 100 FOOT DME/P ACCURACY,
           13.5 FOOT AZIMUTH ACCURACY, AND 2 FOOT ELEVATION
           ACCURACY

	Azimuth to Elevation Distance (Feet)				
Category	6000	7000	8000	9000	10000
I	All	All	All	All	All
II	0	0	0	0	0

TABLE 12. MAXIMUM AZIMUTH STATION OFFSETS FROM 2 SIGMA
           VERTICAL ERROR DATA FOR 40 FOOT DME/P ACCURACY,
           13.5 FOOT AZIMUTH ACCURACY, AND 2 FOOT ELEVATION
           ACCURACY

	Azimuth to Elevation Distance (Feet)				
Category	6000	7000	8000	9000	10000
I	All	All	All	All	All
II	All	All	All	All	All

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